Optimizing Solar Thermal Power Plants: Influences on Parabolic Mirror Shape Accuracy

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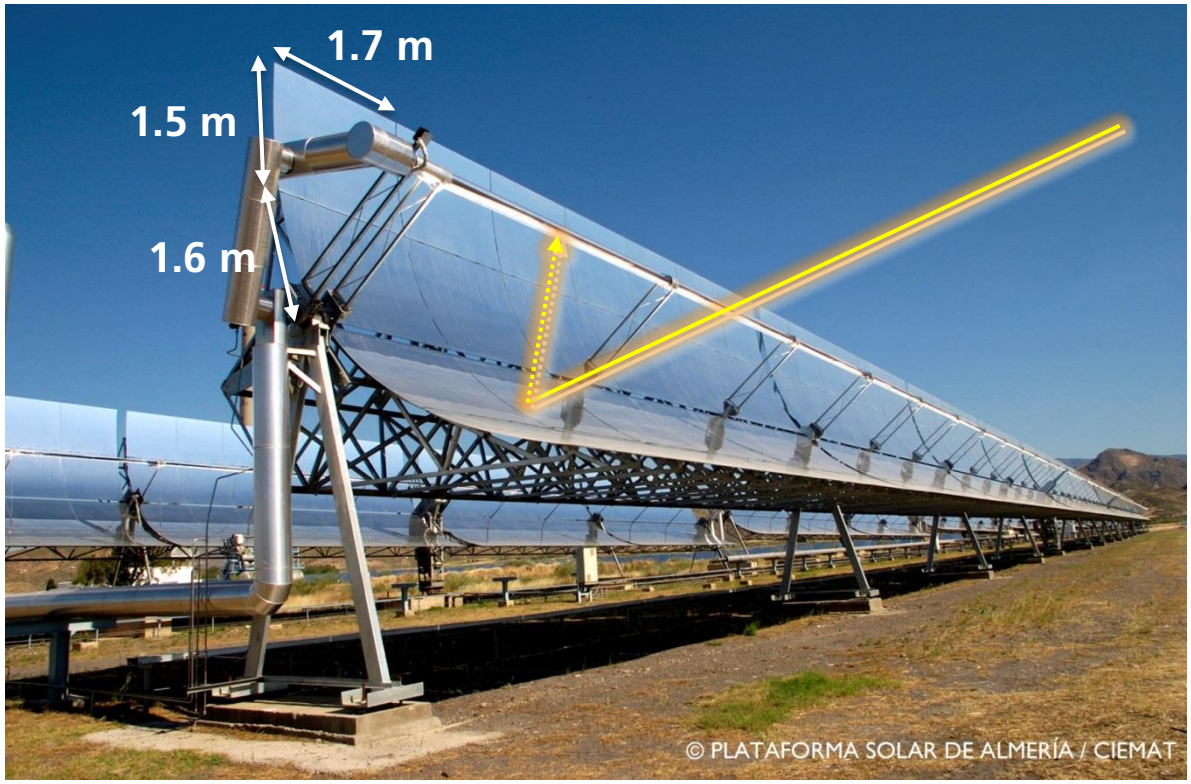
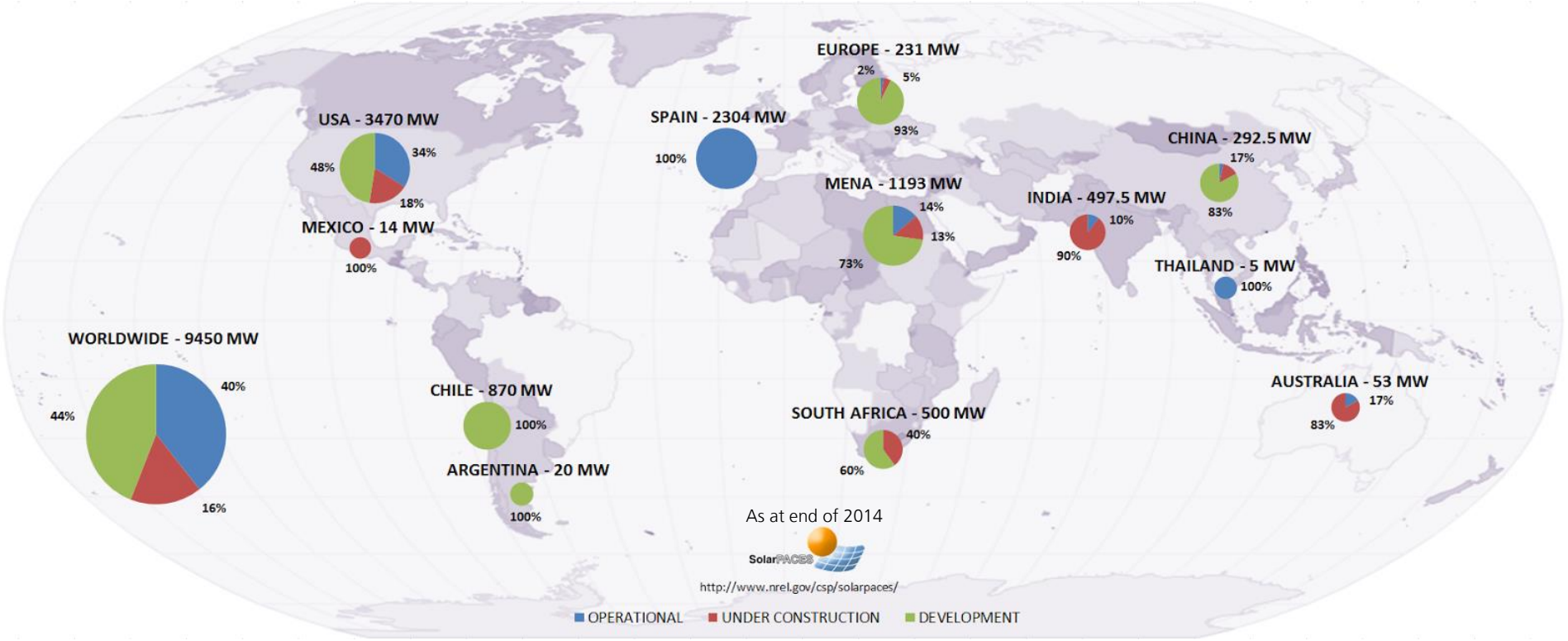
Parabolic Trough Solar Collector

Concentrating Solar Power (CSP)



- Parabolic mirrors concentrate sunlight on absorber, where a heat transfer fluid is heated up to 400°C
- Collector tracks the sun over the day
- Heat is used in heat exchanger to directly generate electricity or stored in thermal storage
- Pioneers of technology:
  - USA
  - Spain
  - Morocco
  - South Africa
  - …

Concentrating Solar Power Technology



Parabolic Trough

Linear Fresnel

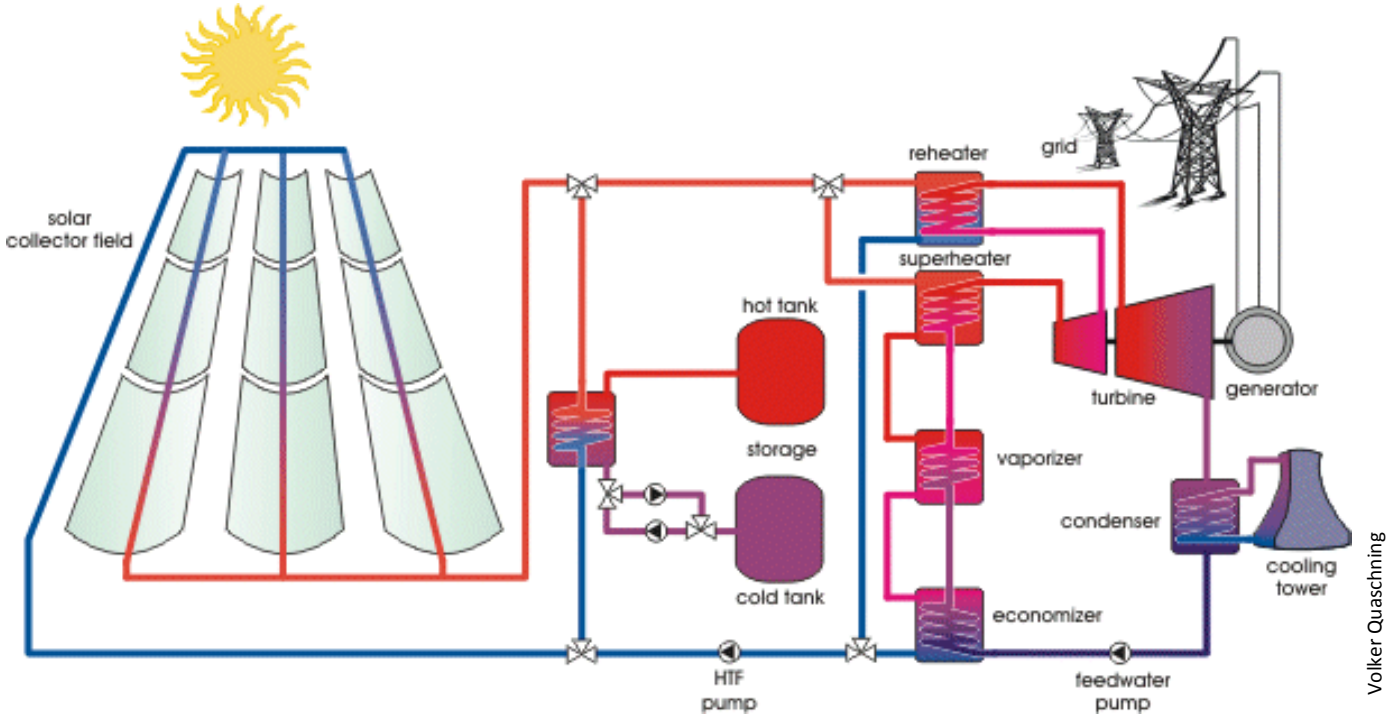
Dish-Stirling

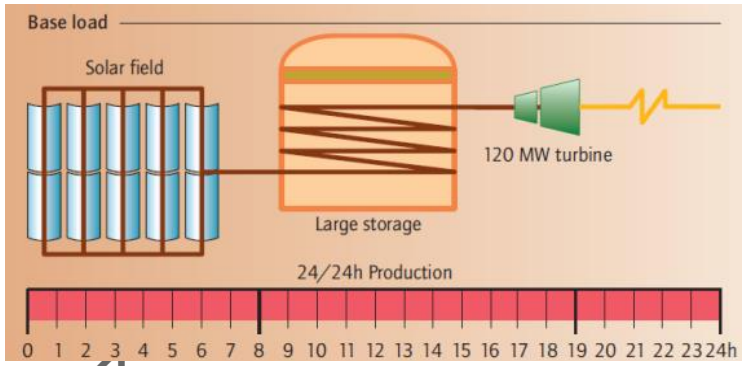
Solar Tower

Andasol, Andalusia, Spain (since 2008)

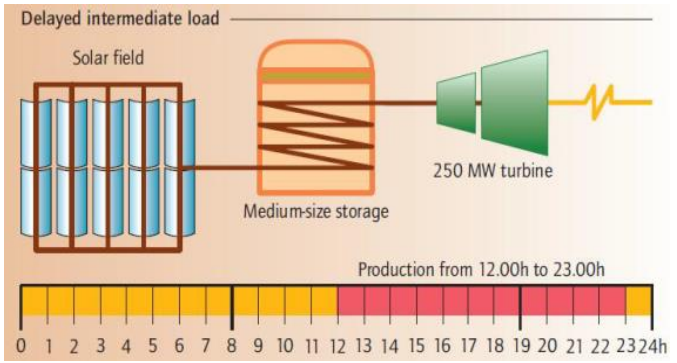
150 MW_{el} , 600 000 mirrors, 1.5 mill m^2 solar field, 8 h Thermal Storage

Parabolic Trough Solar Power Plant



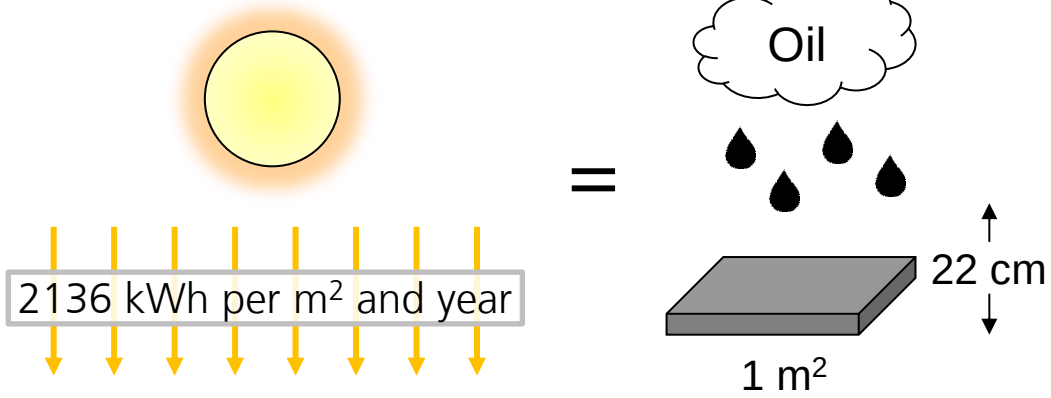


Modular configuration possible



Cost Optimization for CSP plants

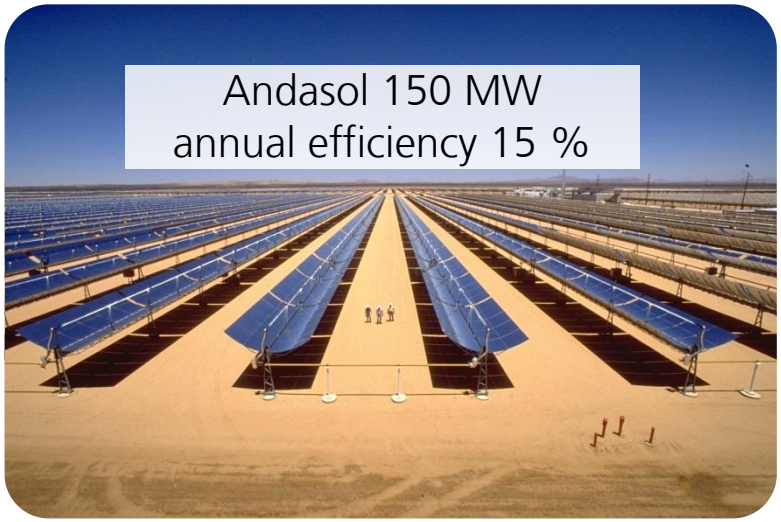
Reduction of optical losses

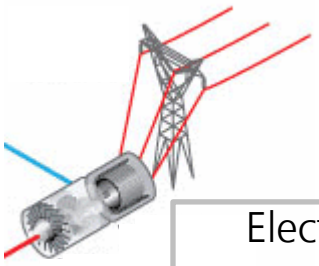


Loss in revenue (30 years): 17 mill €

Loss in revenue (1 year): 580 000 €

1 % loss: 4.8 GWh



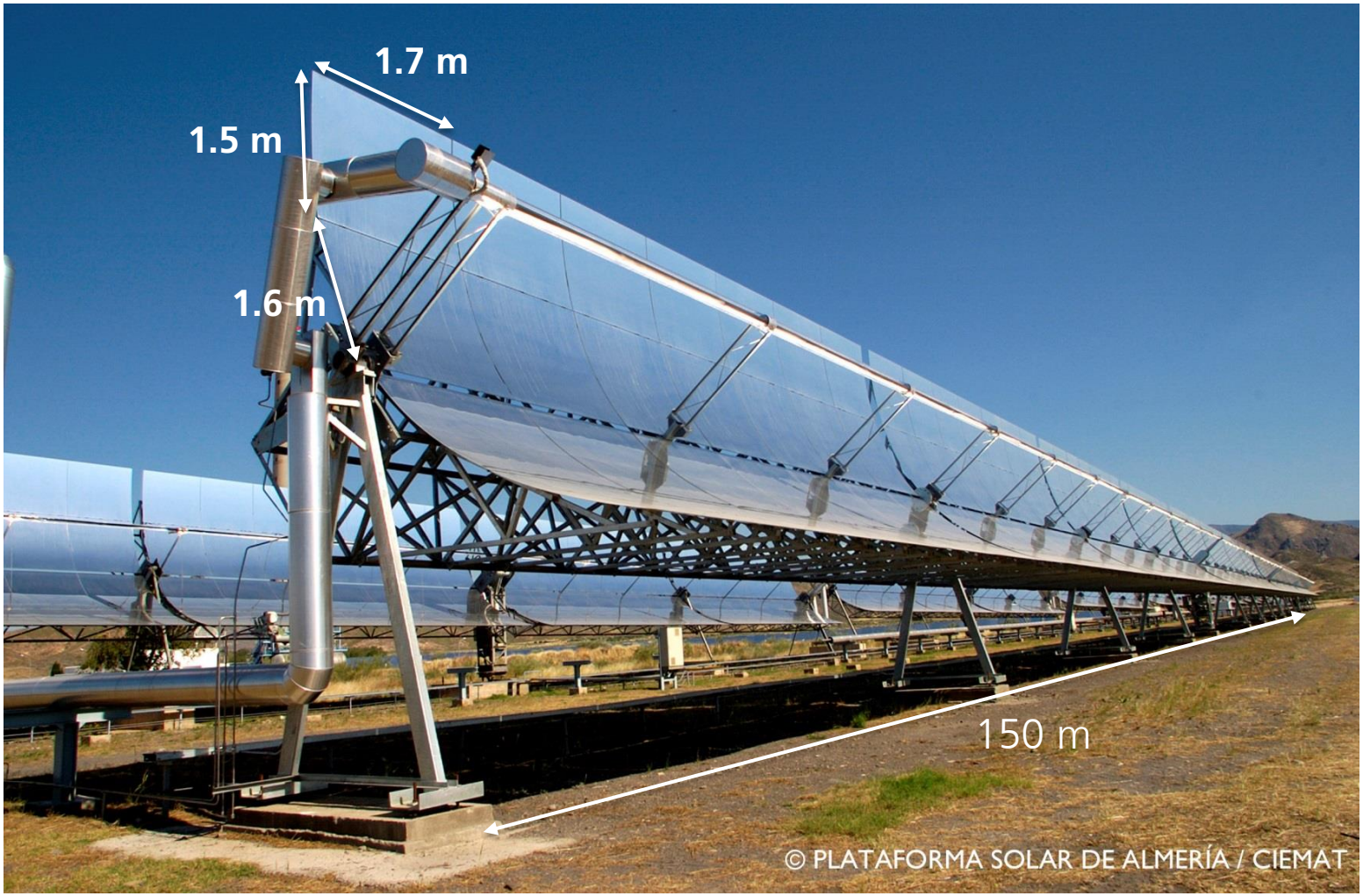


Electricity provided per year: 480 GWh

feed-in tariff: 0.12 € /kWh

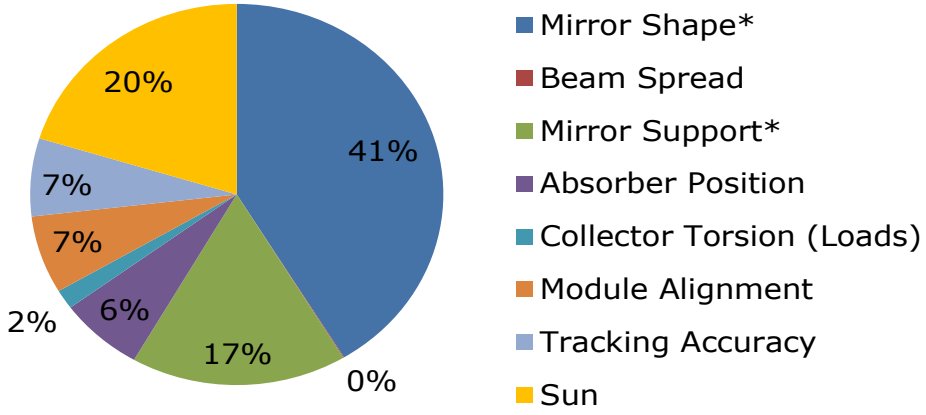
Revenue: 58 mill €

Parabolic Trough Solar Collector (Euro Trough)



Total beam width

RP3 mirror, standard quality



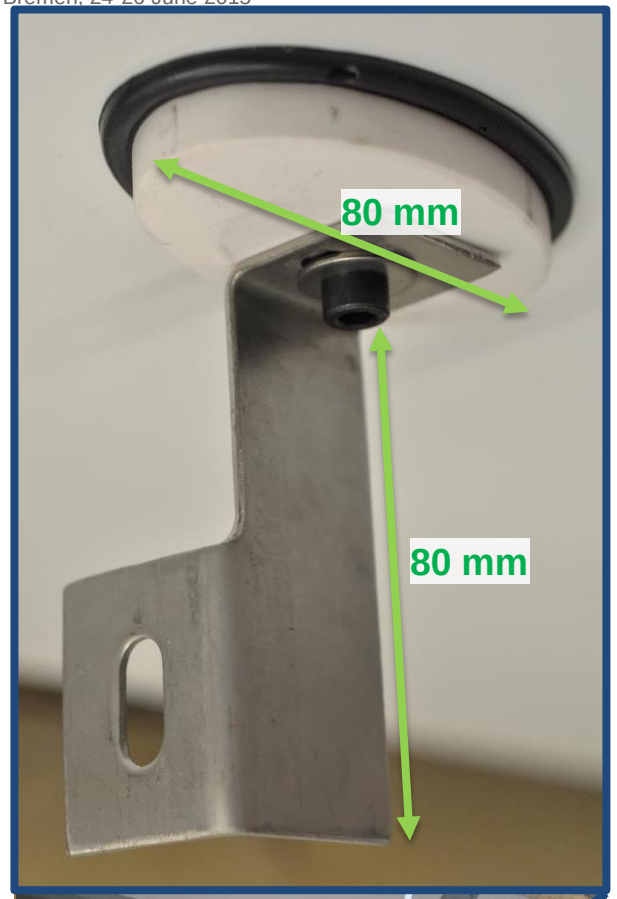
	σ in mrad	$a_i\sigma^2$ in mrad
Mirror Shape*	2.5	25
Beam Spread	0.2	0.04
Mirror Support*	1.6	10.24
Absorber Position	2	4
Collector Torsion (Loads)	1	1
Module Alignment	2	4
Tracking Accuracy	2	4
Sun	3.5	12.25
Total	**7.8**	**60.53**

Combination of standard deviations to total beam width:

$$\sigma_{\text{total}}{}^2 = \sum_i a_i \cdot \sigma_i{}^2$$

Motivation & Aim of study

Improving Mirror Shape Accuracy



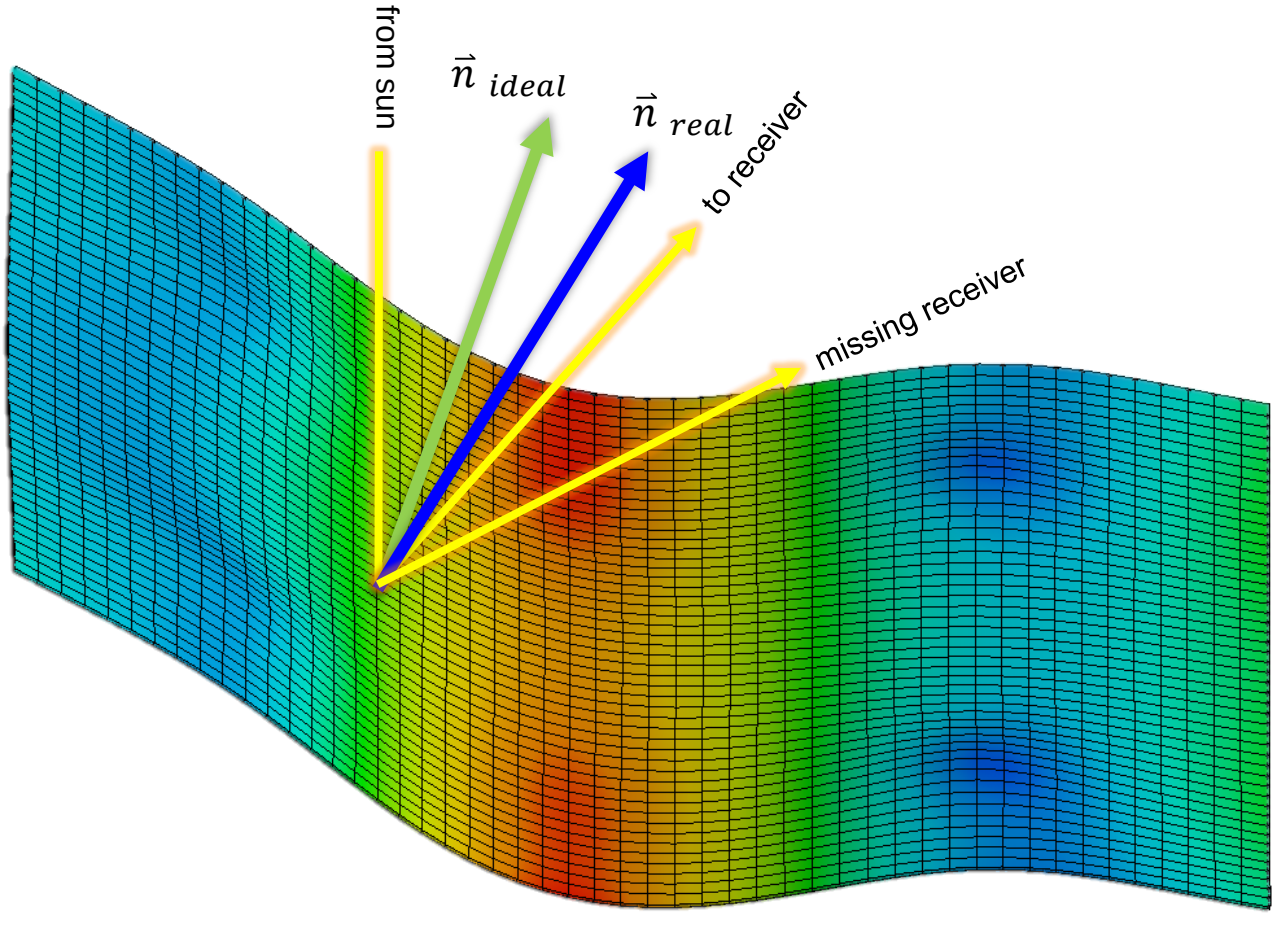
Causes of mirror deformations

- Mechanical stress
- Dead load (depending on collector angle and type and stiffness of support structure)
- Reaction forces from mirror mounting elements
- Additional forces due to mounting inaccuracies

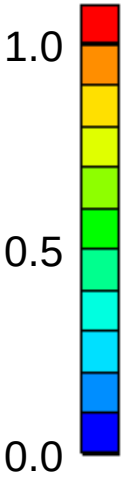
Possible outcome & Research goals

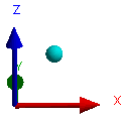
- Influences on mirror shape in collector are better understood
- Performance prediction (influence on annual yield), e.g. influence of deformation due to collector orientation when tracked over the day
- Production tolerances for optical components of solar collectors updated
- Structural improvements, e.g. six instead of four mirror mounting points

Quality Parameter: Slope Deviation



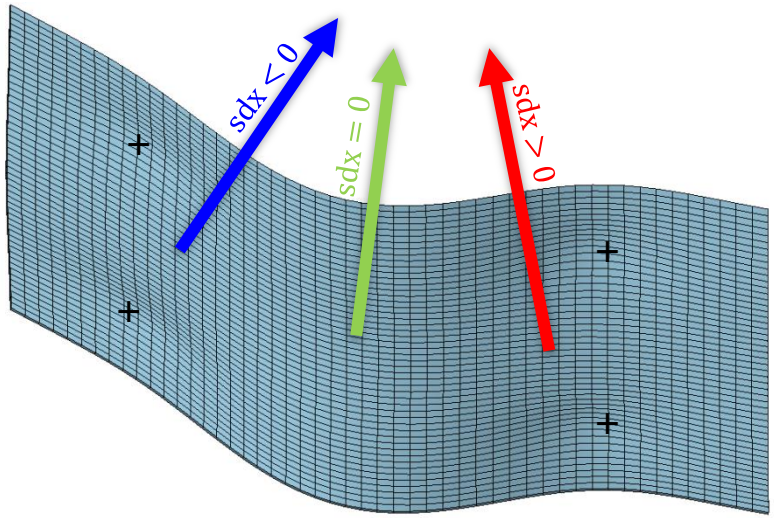
Total Deformation
in mm



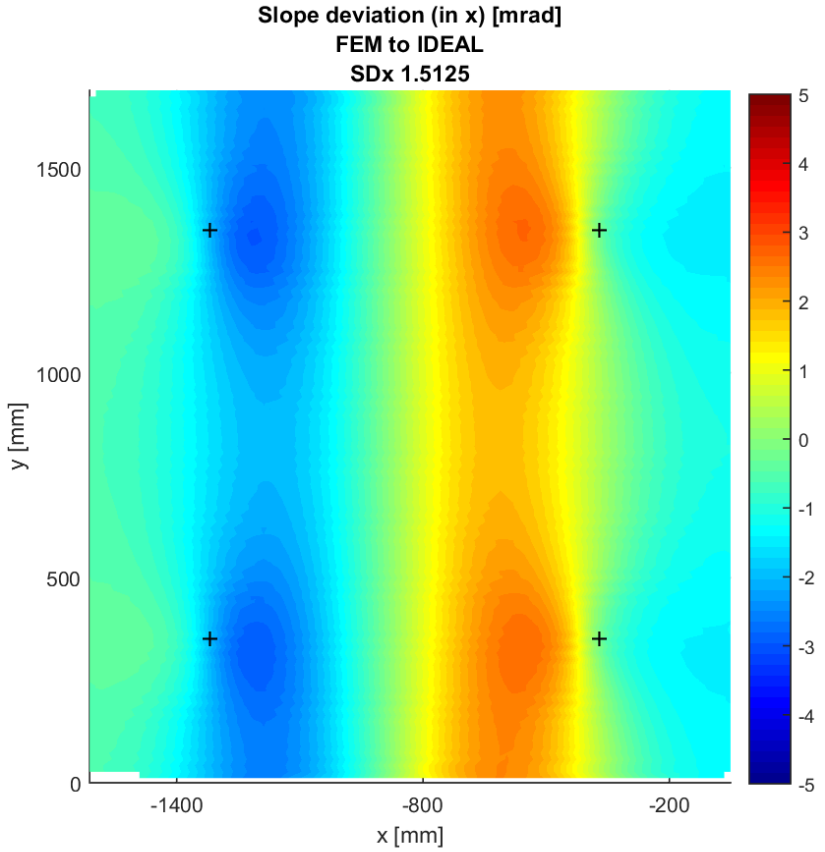


displacements scaled 150x

Quality Parameter: Slope Deviation



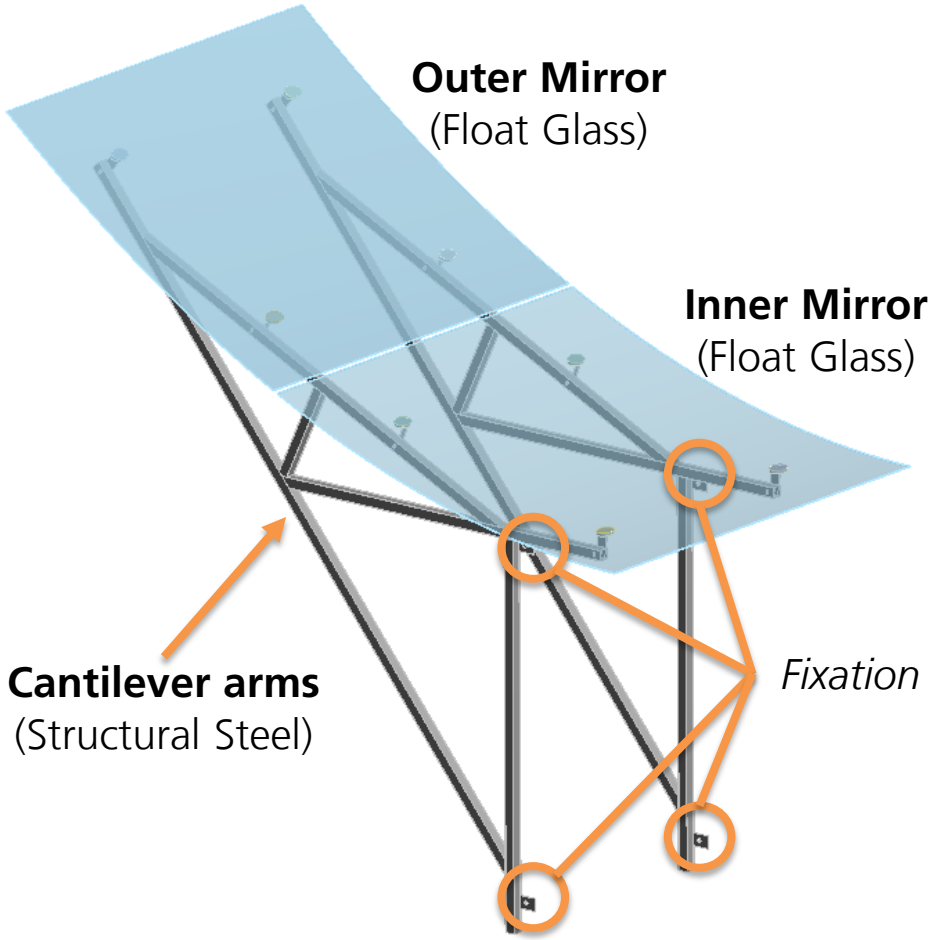
$$\mathrm{sdx}_{(k)} = \sphericalangle\left(\vec{n}_{\mathrm{real},xz}{}^{(k)}, \vec{n}_{\mathrm{ideal,xz}}{}^{(k)}\right)$$



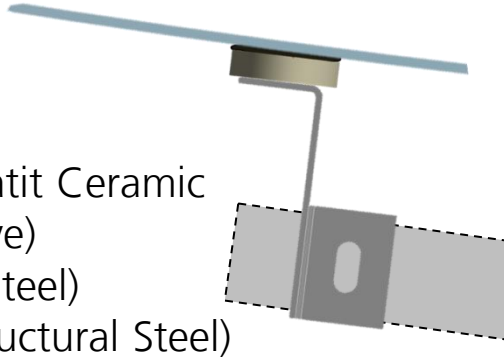
$$\mathrm{SDx} = \sqrt{\sum_{k=1}^{n}\left(\mathrm{sdx}_{(k)}{}^{2} \cdot \frac{a_k}{A_{total}}\right)}$$

goal: < 2 mrad $\approx 0.1°$

Finite Element Model (Euro Trough Solar Collector)



Side view of mirror mounting:



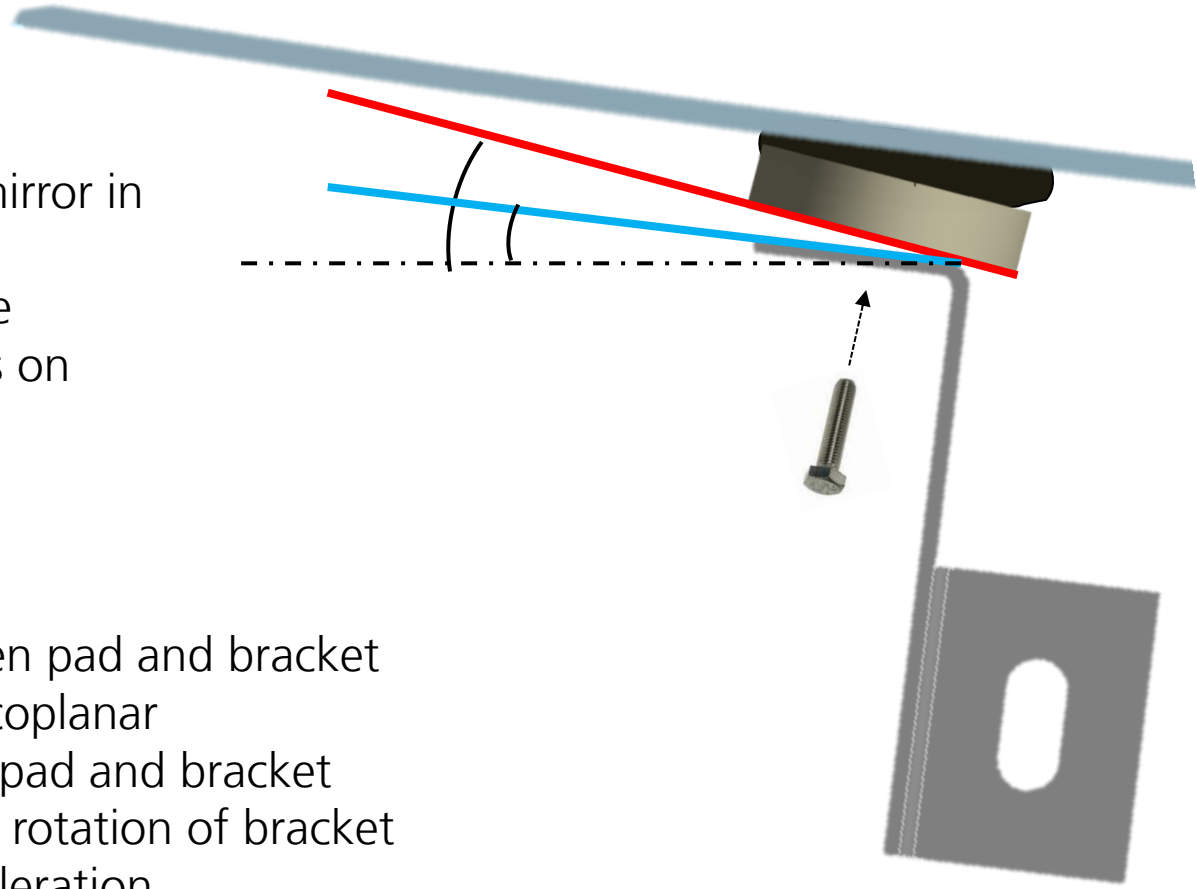
Mirror (Float Glass)
Mounting Pad (Steatit Ceramic with Silicone Adhesive)
Bracket (Structural Steel)
Cantilever Arm (Structural Steel)

- Component-wise acceleration for simulation of dead load in different collector positions
- Rotational and translational joints as well as contact modification for simulation of mounting inaccuracies

Limitations

- No screws or other connecting elements included yet
- Torque-Box not included yet

Simulation: Assembly of mirror on support structure



Reality

1. Pads glued to rear site of mirror in factory
2. Delivery to construction site
3. On-site assembly of mirrors on support structure

Simulation in ANSYS

1. Deactivate contact between pad and bracket
2. Rotate pad until surfaces coplanar
3. Activate contact between pad and bracket
4. Perform displacement and rotation of bracket
5. Activate gravitational acceleration

Automatic workflow for evaluating mirror shape

Parameter

Displacements → *Mirror shape* → *Optical performance* → *Postprocessing*

Results

ANSYS

Displacement of FE-Nodes for specified loads and boundary conditions

MATLAB

Processing of displacements to obtain values describing mirror shape accuracy

SPRAY

Ray tracing based on surface normal vectors

MATLAB

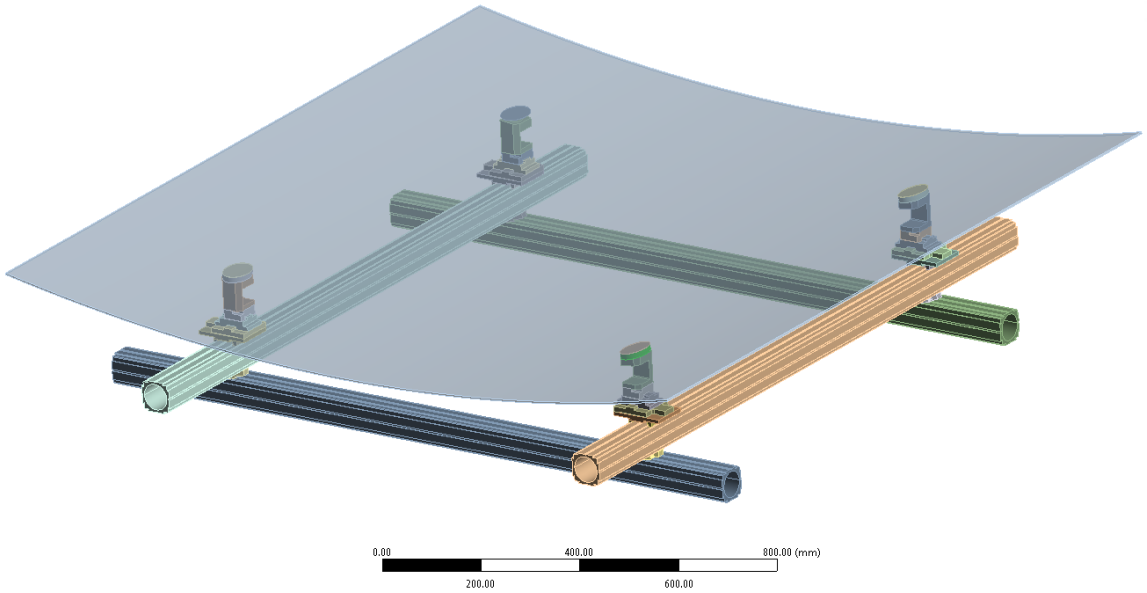
Visualisation of results and estimation of impact on annual yield

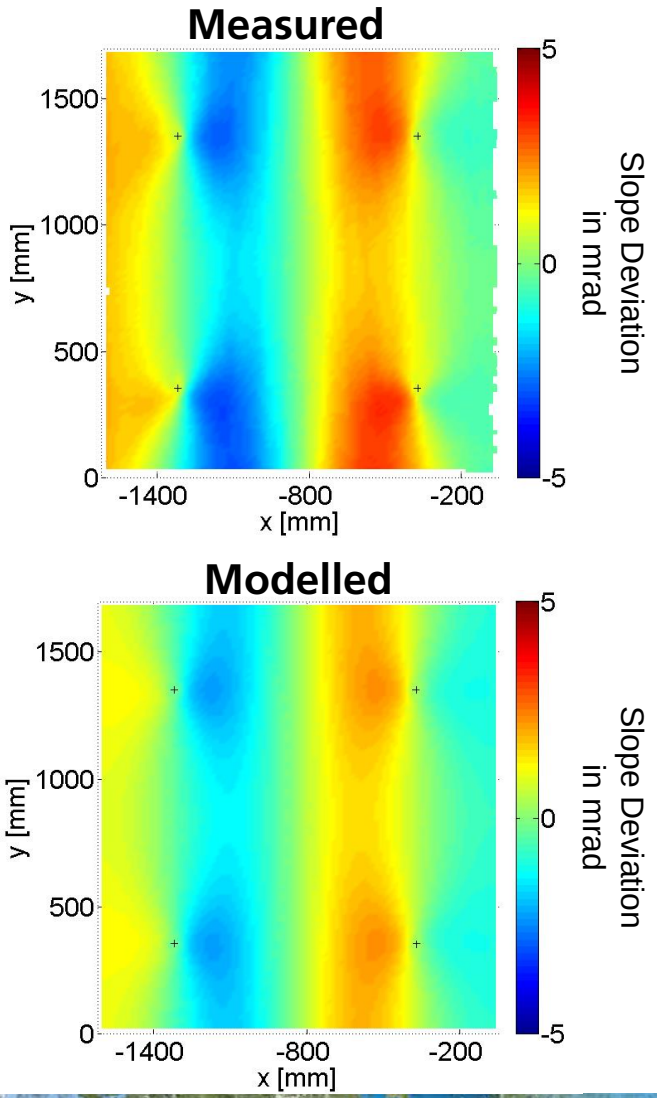
ANSYS-Automation via…

… Mechanical APDL → faster evaluation (for simpler models or optimization processes)

… Workbench Journal → supports workbench functionality

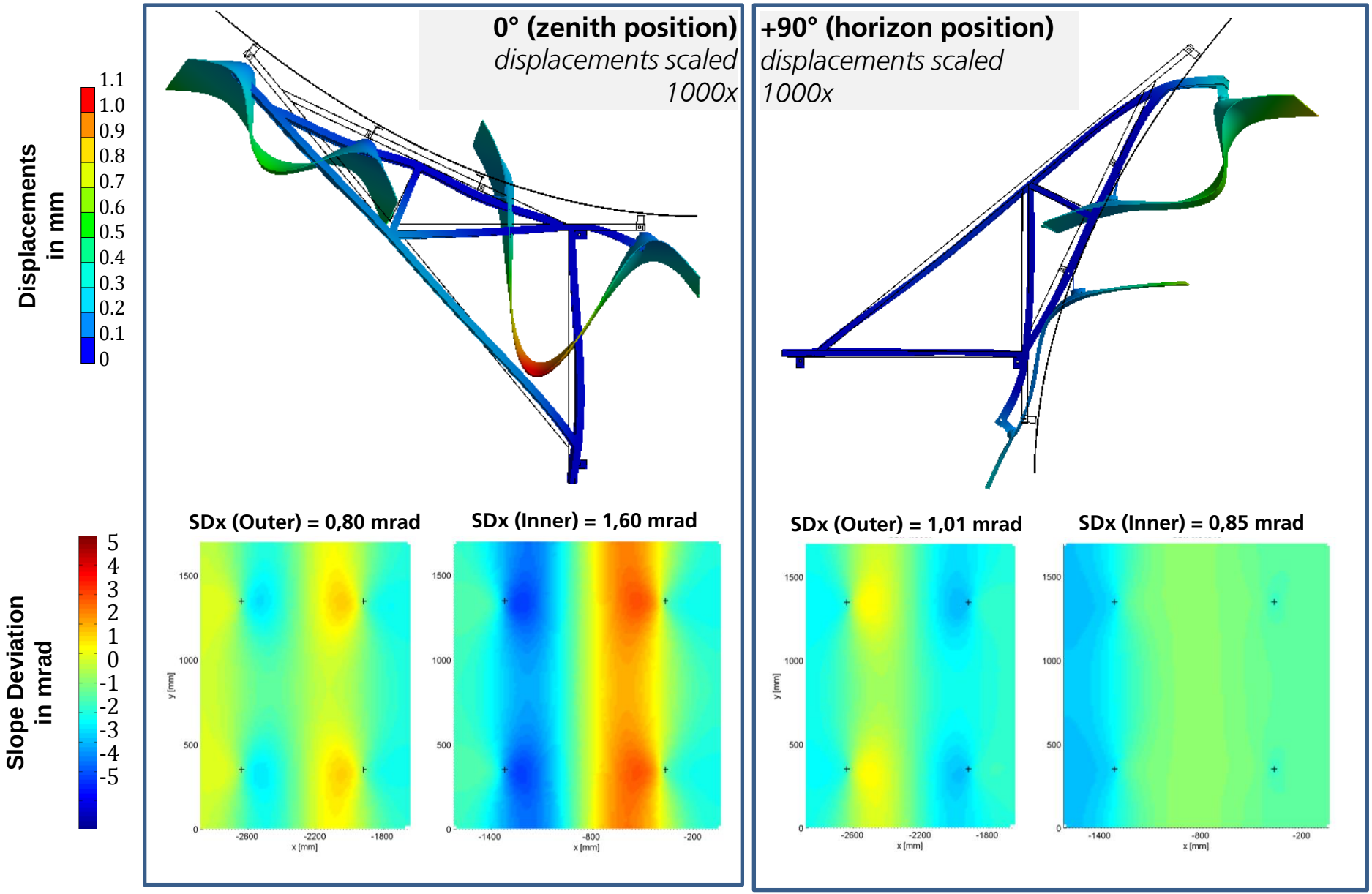
Model validation (mirrors in laboratory setup)



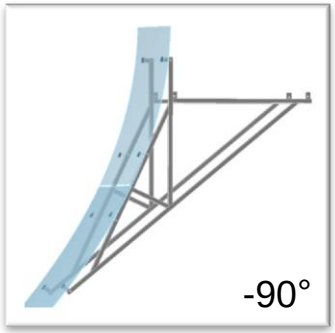


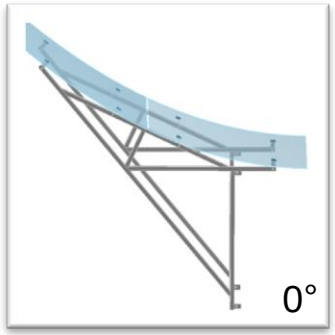
Validation of FE-Model already done for laboratory setup
Internal material stress measured and subtracted from measured case

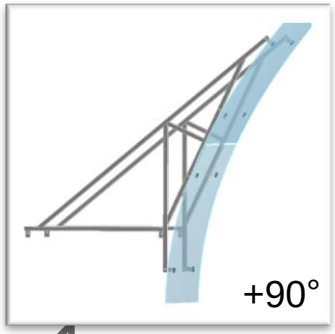
Influence of collector orientation

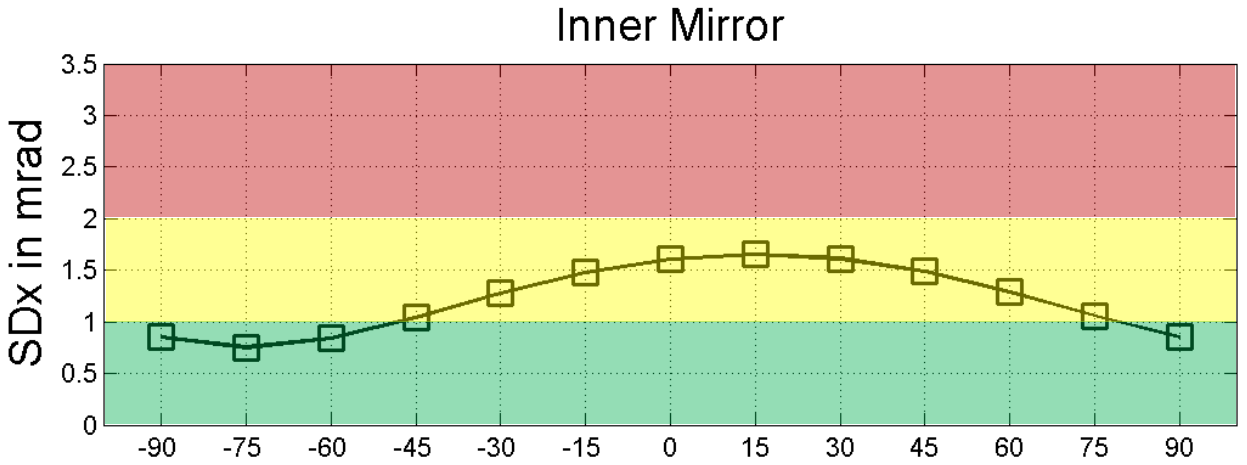


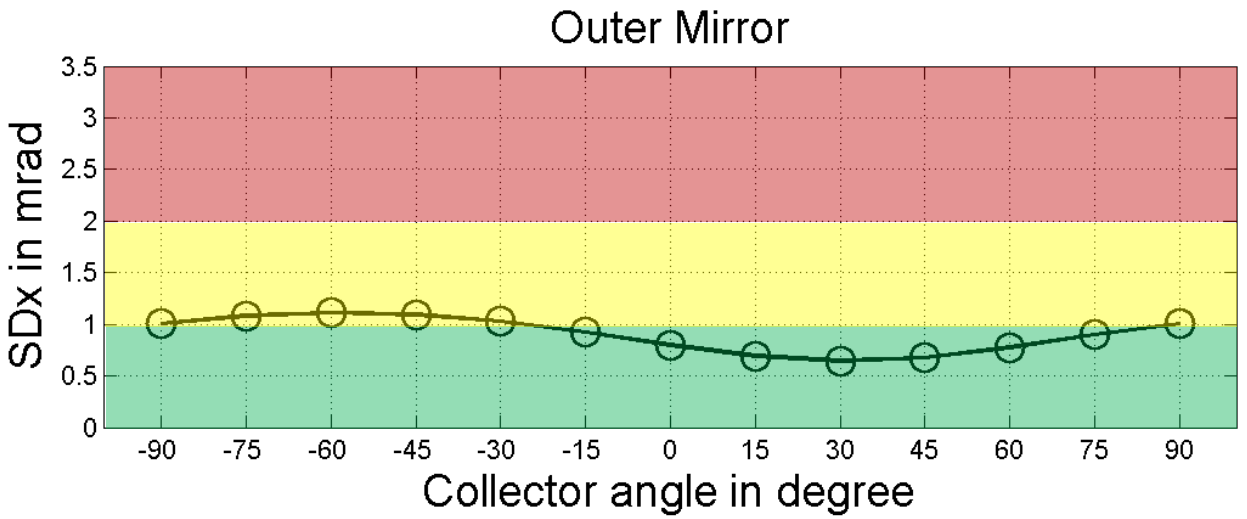
Influence of collector orientation on mirror shape





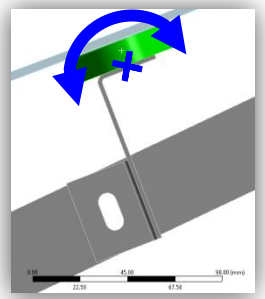




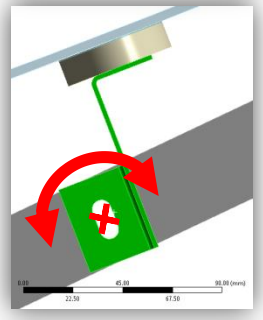


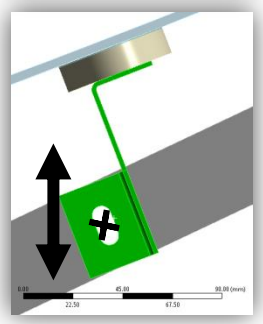
Dead load + mounting inaccuracies

Two brackets with deviations, collector in zenith position

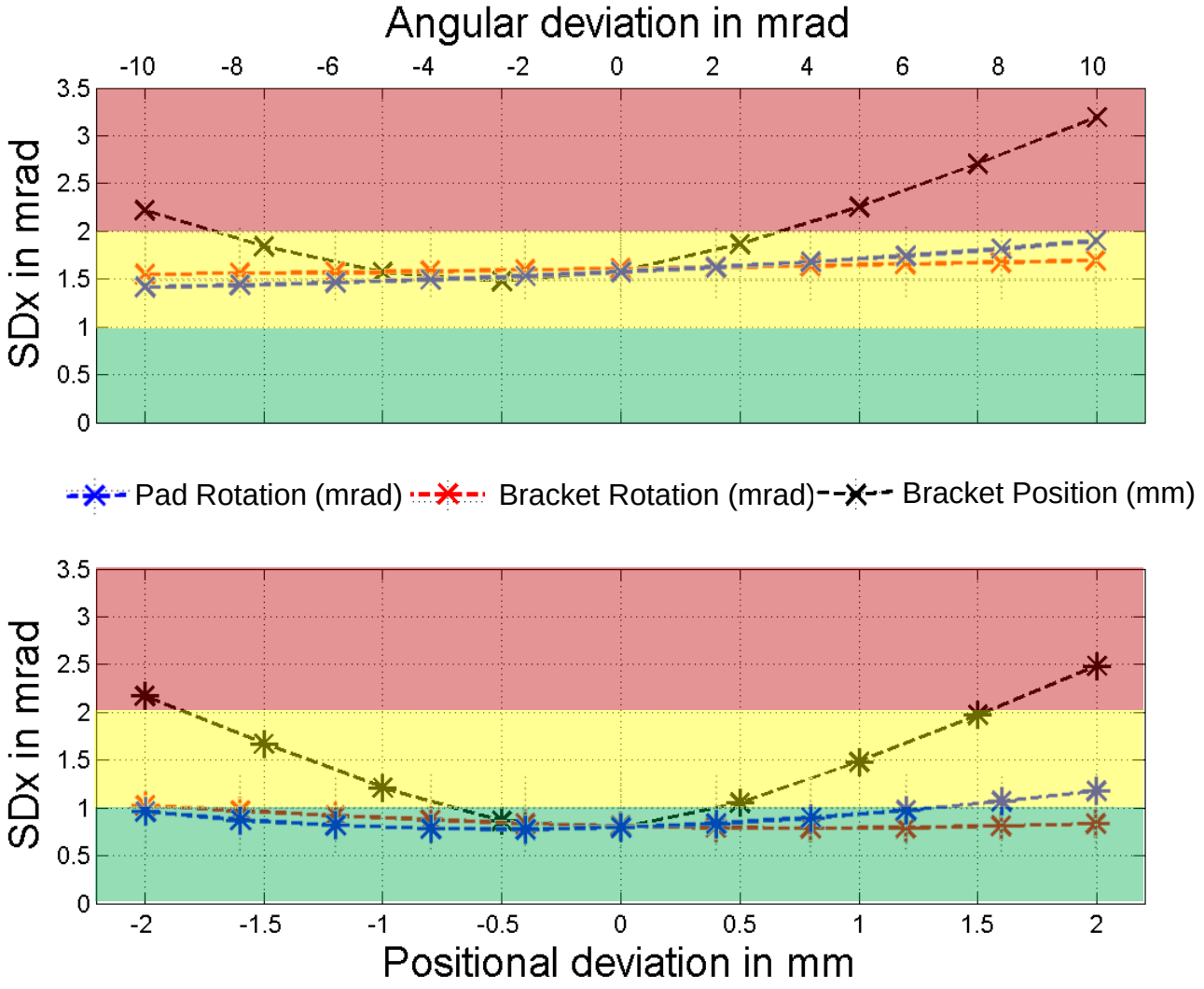


Inner Mirror





Outer Mirror



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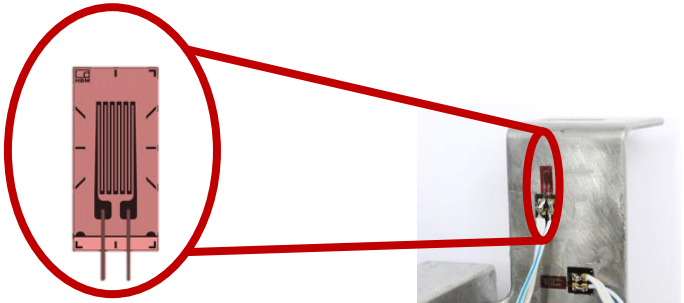
Summary and Further Steps

Slope Deviation (RP3 Inner Mirror)

Dead load	1.65 mrad
Dead load + 10 mrad angular deviation of Z-brackets	1.70 mrad
Dead load + 10 mrad angular deviation of pads	1.91 mrad
Dead load + 2 mm positional deviation of Z-brackets	3.20 mrad

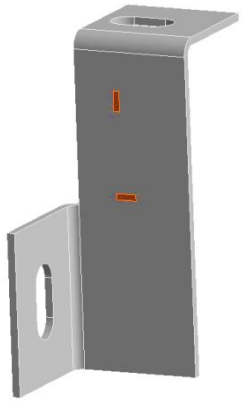
Different values for parameter result in different slope deviation

Use **optimization algorithm** to find parameter that have lead to measured mirror shape



Use of strain gauges to validate FE-Model

Reality



FEM

Conclusion & Outlook

- Finite-Element-Analysis with different loads and boundary conditions
  → useful method for predicting mirror shape deformation
- Impact of loads on resulting slopes of the parabolic mirrors
  → Focus quality affected; less energy on absorber
  → Impact on electricity production & annual yield

- Performance prediction for solar power plant (Influence on annual yield)
- Deriving design criteria and tolerances for concentrating collectors
  - optimizing mirror shape
  - specifying tolerances for assembly
  - increased competitiveness of CSP technology

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Thank you for your attention

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References

[1] Meiser, S.; Kleine-Büning, C.; Uhlig, R.; Lüpfert, E.; Schiricke, B.; Pitz-Paal, R. (2013), „Finite Element Modeling of Parabolic Trough Mirror Shape in Different Mirror Angles“, J. Sol. Energy Eng., 135(3):031006-031006-6

[2] Meiser, S.; Schneider, S.; Lüpfert, E.; Schiricke, B.; Pitz-Paal, R. (2015);
Evaluation and assessment of gravity load on mirror shape of parabolic trough solar collectors“, 7th International Conference on Applied Energy, Abu Dhabi, United Arab Emirates